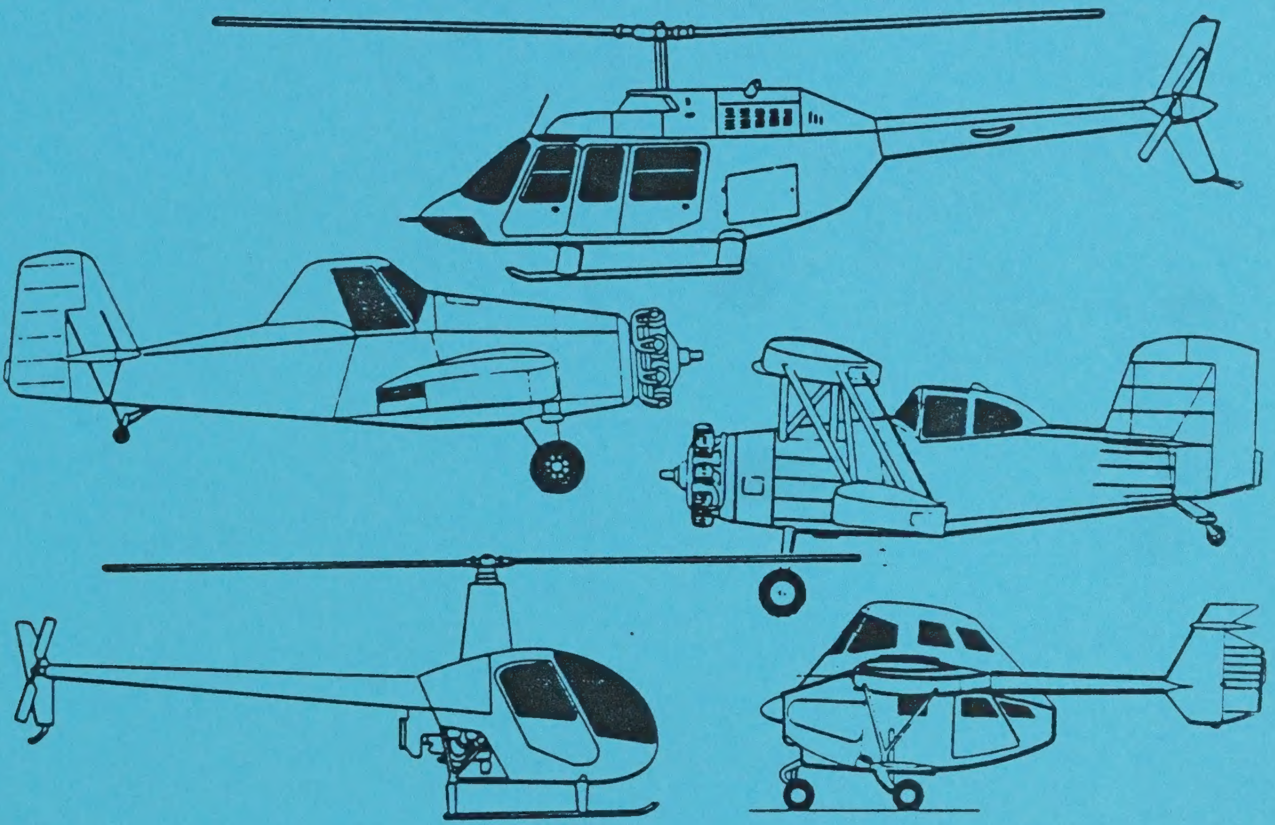
United States
Department of
Agriculture

Forest Service

Equipment
Development
Center

Missoula, MT.

A Method for Comparing Cost & Productivity of Aerial Spray Delivery



November 1984
3400—Forest Pest Management
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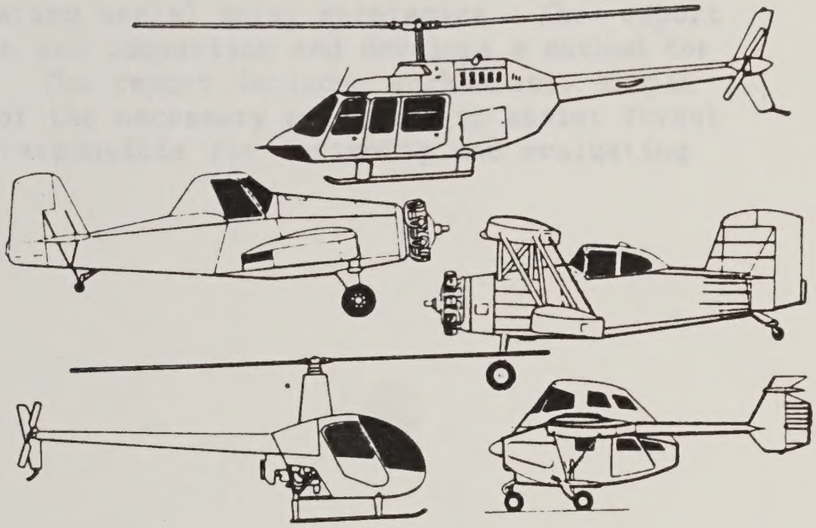

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ABSTRACT

An integral part of the Forest Service Insect and Disease Program is the design of aerial spray programs. Designing such programs requires a method of evaluating and comparing aerial spray strategies. This report defines measures of evaluation and comparison and develops a method for calculating these quantities. The report includes worksheets, sample problems, and the derivation of the necessary equations to assist Forest managers and others who are responsible for designing and evaluating aerial spray operations.

A report on Technological Improvements (TI) Project 3E32P44, Spray Deposit Assessment, sponsored by the Forest Pest Management Staff and State and Private Forestry.

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An integral part of the Forest Service Insect and Disease Program is the design of aerial spray programs. Designing such programs requires a method of evaluating and comparing aerial spray strategies. This report defines measures of exposure and comparison and develops a method for calculating these quantities. The report includes an example, sample problems, and the derivation of the necessary equations to assist Forest managers and others who are responsible for designing and evaluating aerial spray operations.

CONTENTS

Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

INTRODUCTION

In an aerial spray operation, an aircraft applies a pesticide to a specific target, usually an insect or plant infestation. Because forest target areas (fig. 1) are large, inaccessible, and remote, spraying is a major task that requires preparation and planning. Planning requires the ability to compare spray delivery systems. This report presents methods that will enable the Forest manager to make such comparisons.

Two measures of effectiveness of the delivery of an aerially applied spray are the spray productivity and the spray efficiency. Spray productivity is the area sprayed per hour and is the quotient of the area sprayed divided by the total operational time. Spray efficiency is the ratio of the actual spraying-time to the total-operational-flying-time.

This report presents a procedure for calculating both measures of effectiveness. Readers may select the measure most appropriate for their spray operations. An example of the use of the procedure as a planning aid is also presented.

The estimation of the productivity, efficiency, and cost of an aerial spray operation is based upon an accounting of the completion times of the various phases of the spray operation. These times and their interrelationship are shown in figure 2.

Total Operational Time = Flying Time + On the Ground Time

Flying Time = Ferrying Time + Spraying Time + Turning Time + Touchup Time

On the Ground Time = Loading Time + Equipment Adjustment or Repair Time + Aircraft Repair Time

Figure 2.--Operational times and their relationship.

The calculation of the times requires a specification of the flight paths. This specification must be made with due recognition of the variation in topography and the environmental constraints. As a result, the flight paths are usually curved and not all of the same length. This is in contrast to the straight spray paths that usually characterize spraying food crops where the target areas tend to be flat, of uniform height, and rectangular in shape. The determination of the flight time required to spray a forest target must take into account the variation in spray path lengths. This report presents a modification of the Baltin-Amsden[1] method of calculating the efficiency, the productivity, and the cost of an aerial spray operation. The modification allows for irregularly shaped and topographically varied target areas.

1/ Amsden, R. C. (1959). The Baltin-Amsden Formula. Agricu. Aviat. 2(3),95.

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(Figure 2.

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Engine	Adjustment or Repair Time	+	[illegible]

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Figure 1.--Example of forest target area.

Some costs are not included in the efficiency and the productivity calculations. These costs are due to: ground transportation of fuel and pesticide, equipment maintenance, rental and/or purchase of equipment and supplies, personnel, services, overhead, evaluation, and administration. Because these costs are not accounted for in the calculation, the results should be used to compare only the direct operational spraying costs for different spray tactics.

NOTATION

a_r = pesticide application rate, in gallons per acre or in liters per hectare

A_s = area to be sprayed, in acres or hectares

c_r = conversion constant in pesticide flow rate calculation

c_s, c_f, c_ℓ, c_t, and c_u = the hourly costs of spraying, ferrying, loading, turning, and touching up respectively

C_ℓ, C_o = the total costs of loading and flying respectively

C_T = total operation cost

d_a = total auxiliary ferrying distance from permanent airbase to or from helispot, in miles or kilometers

d_f = ferry distance from spray area to or from helispot or airbase for a given cycle, in miles or kilometers

D_f = total direct spray ferry distance, for all cycles from helispot or airbase to and from spray cycle areas, in miles or kilometers

d_s = spray distance in a single cycle, in miles or kilometers

D_s = total spray distance, in miles or kilometers

EFF= efficiency of spraying, i.e., the ratio of the actual-spraying-time to the total-operational-spraying-time, in percent

f_r = pesticide aircraft spray system flow rate, in gallons per minute or in liters per minute

k_u = proportionality constant relating the touchup time to the sum of the total spraying time and the total turning time; usually, $k_u = 0.1$

L= length of rectangular spray area in miles or kilometers

N_a= number of turns used in auxiliary flying

N_c= total number of spray cycles

N_f= number of turns required in ferrying

N_s= number of turns required to spray the target area

N_t= total number of turns required to complete the aerial spray operation

PROD= productivity in acres or hectares sprayed per hour

R_t= operation cost per hour

R_a= operation cost per acre or per hectare

Q_f= pesticide tank capacity, in gallons or liters

s_w= swath width, in feet or meters

T_f= total ferry time, in minutes

T_o= total actual flying time, in minutes

t_ℓ= average time to load and refuel between spray cycles, in minutes

T_ℓ= total loading time, in minutes

T_s= total actual spraying time, in minutes

T_t= total turning time while spraying, in minutes

t_t= time to make a single turn, in seconds

T_T= total operation time, in minutes

T_u= total touchup time, in minutes

v_f= ferry airspeed, in miles per hour or kilometers per hour

v_s= spray airspeed, in miles per hour or kilometers per hour

W= width of rectangular spray area in miles or kilometers

ASSUMPTIONS

It is assumed that the items and the values of the variables listed below are available or known:

1. A topographic map showing the target and the surrounding area.

2. A drawing to a scale sufficient to permit the simultaneous location of helispots and/or airfields and the target area.

3. The pesticide application rate, a_r; the pesticide tank capacity, Q_f; and the spray speed of the aircraft, v_s.

4. The loading time per cycle, t_ℓ.

5. The hourly costs of spraying, c_s; ferrying, c_f; loading, c_ℓ; and turning, c_t.

The calculations of the productivity and the efficiency are based on the assumptions that:

1. The amount of pesticide carried each cycle is the same.

2. The swath width, s_w, is the same for each swath.

3. The operations accounted for in the cost estimate are:

   a. Loading and the fueling of the aircraft.

   b. Ferrying of the aircraft to and from the loading strip and between swaths (if necessary).

   c. Spraying and touching up.

   d. Turning.

4. The aircraft is loaded and fueled at the local strip or pad. Loading time is defined to be the time from "wheels down" to the time of "wheels off."

5. The total touch time, T_u, is directly proportional to the sum of the spraying and the turning times.

6. The decision to terminate a spray cycle is independent of the fuel supply and the fuel consumption rate of the aricraft. Terminating a spray cycle is due solely to the exhaustion of the pesticide contained in the spray tank.

7. No allowance is made for turning time when calculating the touchup time.

8. No allowance is made for the fact that the final load of the operation may only be partially used. Thus, the time required to spray the last load is the time required to spray the full load.

TECHNICAL APPROACH

Calculating the spray productivity and the spray efficiency requires the determination of the times required to complete the operations of spraying, ferrying, turning, and loading. In this report only these operations will be accounted for in the determination of the productivity and the efficiency. Spraying is the flying required to actually spray the target area and turning is the flying necessary to realign the aircraft for spraying the succeeding path.

Ferrying is the flying required to fly the spray aircraft from the helispot, local airstrip, or permanent airbase to the spray area and return. Ferrying also includes the nonspray flying necessary to fly from one point in the target area to another without returning to the local base or to the permanent airfield. Such flying is usually done by "jumping" from one portion of the target area to another to again resume spraying. Ferrying also includes flying the aircraft to spots in the target area to begin "touching up" various subareas that may have been missed or omitted.

The determination of the times to complete the various flying operations depends upon the total spray distance, the total ferry distance, the total number of turns, and the total number of loads. In turn, these quantities depend upon the spray path lengths. If the spray area may be suitably approximated by a rectangle and the spray paths are parallel to a side of the rectangle, the spray path length is the length of that side of the rectangle. In this event it is straightforward to determine the total spray path distance.

If the spray area is irregular in shape, the determination of the aforementioned quantities can be made by specifying, on a scaled drawing of the target area, a set of lines which are to be paralleled by the actual spray paths. In the following, these lines will be called spray lines to distinguish them from the actual flight (spray) paths. Figure 3 indicates a typical situation and the dashed lines are spray lines. The actual spray paths are to be flown parallel to and between the spray lines and hence between any pair of adjacent spray lines there may be one or more spray paths. The spray lines are assumed to be drawn close enough together so that the length of a spray path lying between a pair of adjacent spray lines can be assumed to be the same length as the nearest spray line. In figure 3, the pairs of points Y_s, Y_e; and Z_s, Z_e; indicate the beginning and the ending of the spray lines paralleling the road.

A spray path length can then be determined by measurement of the length of the nearest spray line using the scaled drawing. Numbering the spray lines on the target drawing facilitates the accounting of their length.

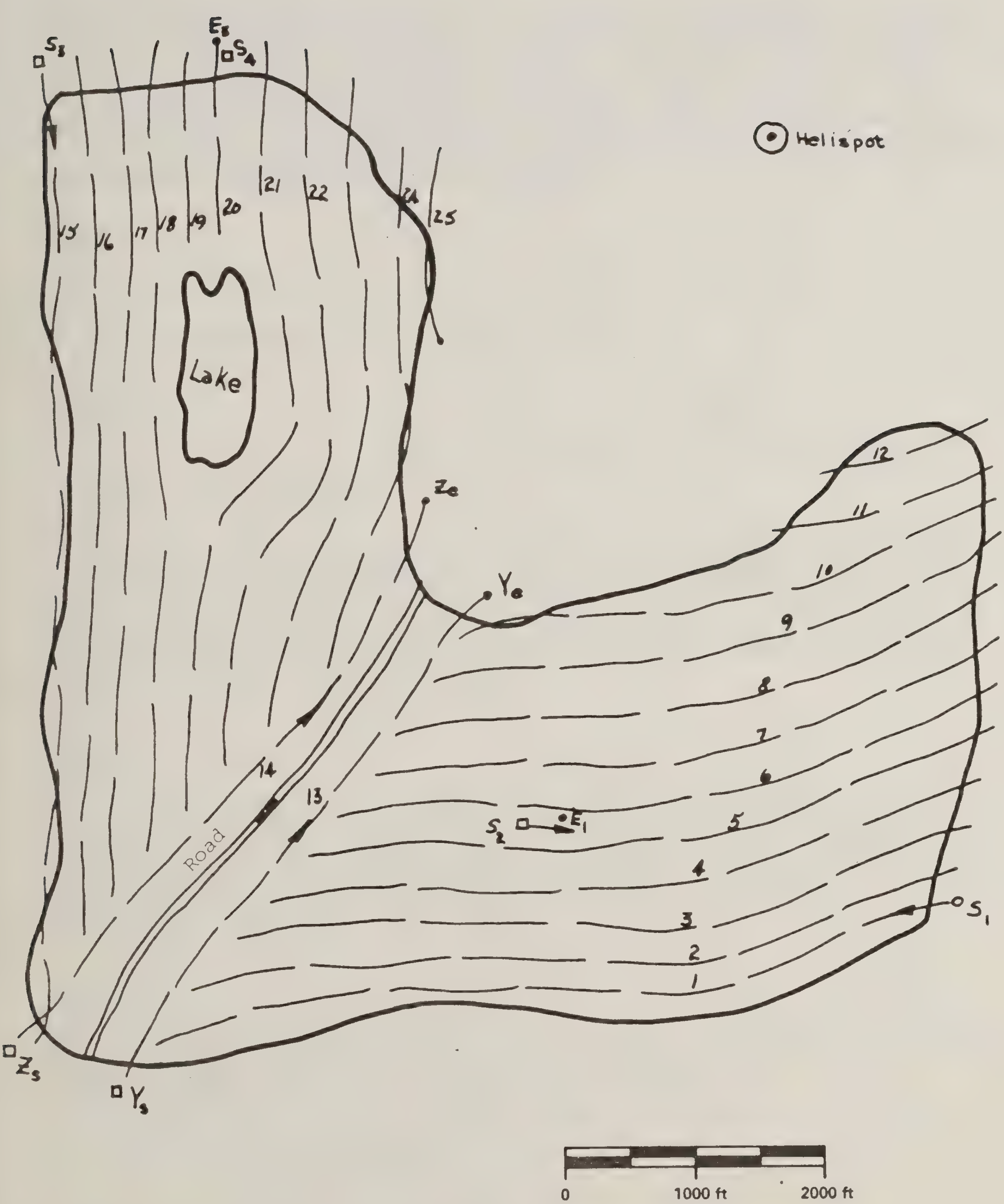

Figure 7.--Example of spray path designation.

CALCULATION PROCEDURE

The following section describes the procedure for calculating the spray efficiency and spray productivity. The procedure is described in some detail to enable the reader to grasp the rationale. The next section consists of a set of blank worksheets that are to be used in their numerical order when performing the calculations. Following the blank worksheets are three completed examples illustrating the calculations and the use of the worksheets in carrying out the calculations.

Step 1.

Determine the area to be sprayed, A_s, in acres or hectares.

A_s can be determined from the scaled drawing.

Step 2.

Determine the spray characteristics and specify the spray equipment to be used in the operation.

The allowable EPA registered pesticides and the application rate are specified by the Forest entomologist. The spray strategist recommends the droplet size distribution and then selects the aircraft type and the associated spray equipment and spray parameters. After the spray parameters have been set, the swath width, s_w, is determined. Assuring the swath width may require preliminary tests.

Step 3.

On a scale drawing of the target area, draw the spray lines. The lines should be drawn with proper regard for topography, local meterological conditions, and such environmental constraints as rivers, creeks, campsites, lakes, etc. Other areas in or near the target area not to receive spray should be clearly identified.

Step 4.

Determine the required pesticide flow rate for the aircraft spray system.

The pesticide flow rate in gallons/minute is given by:

$$f_r = \frac{a_r v_s s_w}{495}$$

The pesticide flow rate in liters/minute is given by:

$$f_r = \frac{a_r v_s s_w}{600}$$

Step 5.

Determine the allowable spray cycle distance, d_s, for each of the spray cycles. d_s is specified in miles or kilometers and is governed by the spray tank capacity, the speed of the aircraft while spraying, and the pesticide flow rate.

The spray distance per cycle in miles or kilometers is:

$$d_s = \frac{Q_f v_s}{60 f_r}$$

Note: The units of the quantities appearing in the above formula must be compatible.

Step 6.

Determine the total spray path length, D_s.

For rectangular-shaped target areas, the number of spray paths is the quotient of the length of the side of the rectangle perpendicular to the spray path divided by the swath width. This number, multiplied by the spray path length, is the total spray distance.

For irregularly shaped target areas, the total length of the spray paths is found by summing the lengths of all spray paths. The number of such paths is that required to cover the target area and is the sum of the numbers of spray paths required to cover the areas between pairs of adjacent spray lines. Each of these numbers is the quotient of the average distance between the pair of adjacent spray lines and the swath width. [These numbers are entered in the appropriate rows of the second column of the table accompanying item 6 (page 19) on the set of worksheets.] The average distance between any pair of adjacent spray lines can be estimated with the aid of a ruler and the scaled drawing of the target area.

The length of the spray path is assumed to be the same length as the length of its nearest neighbor spray line. The length of a spray line may be obtained by measurement from the scaled drawing.

For rectangular-shaped target areas as well as for irregularly shaped target areas, the product of the total length of the spray path and the swath width should be equal to the area of the target. Thus, a comparison of this product with the actual target area provides a measure of the accuracy of the determination of D_s.

Near the end of the spray cycle, the flow rate of the pesticide decreases due to the near emptiness of the pesticide tank. This results in a lesser pesticide dose being sprayed on the end portion of the cycle. The proper dose is assured by respraying the affected portion of the cycle. In the calculation of D_s, no allowance was made for this duplication of spraying. The user may wish to correct for this omission by increasing the calculated value of D_s by an amount proportional to the calculated value.

Step 7.

Determine the number of spray cycles, N_c. N_c is the rounded up quotient of the total spray path length by the spray cycle distance.

$$N_c = \frac{D_s}{d_s}$$

Step 8.

Determine the total spray cycle ferry distance, D_f.

D_f is the sum of the distances, d_f, from the helispot or airport to the starting and ending points of the spray cycles. If the nearby temporary helispots are used, determine the ferry distance from the helispot to the permanent helicopter base. Denote this auxiliary ferry distance by d_a and include this distance in the previous sum. D_f should also include the distances required to ferry the aircraft from one point in the target area to another while not actually spraying. Such flying is usually done when "hopping" from one area to another to touch up the spray area. All of the distances should be obtainable from the scaled spray area layout.

The estimation of the ferry distances to the starting and ending points of a spray cycle requires the location of these points. These locations may be determined by summing successive spray path lengths until the spray cycle distance is obtained. The point on the spray path where this occurs is taken to be the end point of the spray cycle. The summing process can be accomplished most readily with the aid of a ruler and the scaled drawing. The spraying of an area usually requires many spray cycles. Thus errors made in determining the total ferry distance, which is the sum of the ferry distances to and from each starting and ending point, should "average out."

Item 8 (page 21) of the worksheet set provides a tabular form for recording the ferry distances.

Step 9.

Determine the total number of turns, N_t.

N_t is the total number of turns required to complete the aerial spray operation. N_t is the sum of: N_s, the number of turns required to spray the target area; N_f, the number of turns required in ferrying; and N_a, the number of turns used in auxiliary flying such as touching up, observation, etc. N_s is equal to the number of spray paths, N_f may be taken to be twice the number of cycles, and N_a is an ad hoc estimate. N_a may be zero. In the event any of the numbers are not integers, they are to be rounded up. For a rectangular shaped spray area the default value for N_a is 2, which allows for a bit of touching up.

Step 10.

Determine the total ferry time, T_f, the total spray time, T_s, and the total turning time, T_t. These items are each measured in minutes.

T_f is given by

$$T_f = 60 \left(\frac{d_f + d_a}{v_f} \right)$$

T_s is given by

$$T_s = 60 \left(\frac{D_s}{v_s} \right)$$

Note: T_s does not include touchup time. This time is calculated in Step 11 below.

T_t is given by

$$T_t = \frac{N_t t_t}{60}$$

Note: The units of the quantities appearing in each of the above equations must be compatible.

Step 11.

Determine the total touchup time, T_u. T_u is assumed to be proportional to the sum of the total actual spraying time and the total turning time.

T_u is measured in minutes and is given by

$$T_u = k_u \ (T_s + T_t)$$

where k_u is usually taken to be 0.1. The value of k_u may be altered to better reflect the local conditions.

Step 12.

Determine the total loading time, T_ℓ. T_ℓ is measured in minutes and is the product of the total number of cycles and the average loading time per cycle.

$$T_\ell = N_c \ t_\ell$$

Step 13.

Determine the total actual flying time, T_o. T_o is measured in minutes and is given by

$$T_o = T_f + T_s + T_t + T_u$$

Step 14.

Determine the total operation time, T_T. T_T is measured in minutes and is the sum of the total flying time and the loading time.

$$T_T = T_o + T_\ell$$

Step 15.

Determine the total flying cost, C_o. C_o is calculated in terms of the specified hourly costs of spraying, ferrying, turning, and touching up.

$$C_o = (c_s \ T_s + c_f \ T_f + c_t \ T_t + c_u \ T_u) \ /60$$

Step 16.

Determine the total loading cost, C_ℓ.

This cost is determined by the total loading time and the average hourly cost of loading.

$$C_\ell = (T_\ell\ c_\ell)/60$$

Step 17.

Determine the productivity, PROD.

PROD is the ratio of the total area sprayed to the total operation time. PROD is measured in acres per hour or hectares per hour.

$$\text{PROD} = 60\ A_s/T_T$$

Step 18.

Determine the efficiency, EFF.

EFF is measured in percent and is the ratio of the total actual spraying time to the total operation time.

$$\text{EFF} = 100\ (T_s + T_u)/T_T$$

Step 19.

Determine the total cost, C_T.

$$C_T = C_o + C_\ell$$

Step 20.

Determine the hourly operation cost, R_t.

R_t is the quotient of the total cost by the total time.

$$R_t = 60\ C_T/T_T$$

Step 21.

Determine the cost per acre or the cost per hectare, R_a.

R_a is the quotient of the total cost by the total area sprayed.

$$R_a = C_T/A_s$$

INSTRUCTIONS FOR USING WORKSHEET SET

1. Complete Input Data Sheet.

2. Complete calculations in Worksheet Set (pages 17-23).

The calculations are to be done in the order they appear on the worksheet page. The number preceding the individual calculation title refers to the corresponding step number described in the procedure section.

3. If several areas are to be sprayed in the same operation and such parameters as swath width, application rate, flying speeds, costs, etc. are different for each area, it will be necessary to use a separate copy of the complete worksheet set for each spray area, or set of spray areas, that are operationally defined by the different sets of parameters.

Input Data Sheet

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	______
Target Dim**	mi or km	L, W	______
Application Rate	g/Ac or l/ha	a_r	______
Tank Capacity	g or l	Q_f	______
Swath Width	ft or m	s_w	______
Spray Speed	mi/hr or km/hr	v_s	______
Ferry Speed	mi/hr or km/hr	v_f	______
Turning Time	sec	t_t	______
Aux. Ferry Dis.	mi or km	d_a	______
Touchup Const. of Prop.		k_u	______
Spraying Cost Rate	$/hr	c_s	______
Ferrying Cost Rate	$/hr	c_f	______
Turning Cost Rate	$/hr	c_t	______
Touchup Cost Rate	$/hr	c_u	______
Loading Cost Rate	$/hr	c_ℓ	______
Loading Time/Cycle	min	t_ℓ	______

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Worksheet

Some of the calculations are considerably simplified if a rectangular approximation to the target area is permitted. Separate calculation steps for these cases are given.

Step 1. Target Area, A_s

A_s = ______________________ ac or ha

Rectangular shaped spray area

a. L and W in miles

A_s = 640 LW = 640 (_____) (_____) = _____ac

b. L and W in km

A_s = 100 LW = 100 (_____) (_____) = _____ha

Step 4. Pesticide Flow Rate, f_r (g/min or l/min)

$f_r = c_r a_r v_s s_w$

= (_____) (_____) (_____) (_____)

f_r = ______________________g/min or l/min

where: $c_r = \frac{1}{495}$, if a_r in g/ac, v_s in mi/hr and s_w in ft or

$c_r = \frac{1}{600}$, if a_r in l/ha, v_s in km/hr and s_w in m.

Step 5. Spray Distance per Cycle, d_s (mi or km)

$$d_s = \frac{Q_f v_s}{60 f_r} = \frac{(\quad\quad)\ (\quad\quad)}{60(\quad\quad)}$$

d_s = ______________________ mi or km

Note: d_s in mi or km according to the units of Q_f, v_s, and f_r. These units must be compatible.

Step 6. Total Spray Distance, D_s (mi or km)

This calculation is made in accord with the discussion concerning step 6 of the procedures. The accompanying worksheet may be used as an aid. The sum called for at the bottom of the third column is the sum of the total lengths of the associated spray paths. If more than one worksheet is used, D_s is the total of the sums appearing at the bottom of each worksheet. The sum of the numbers appearing in the second column is the required number of turns for spraying (see item 9).

D_s = ______________________ mi or km

Rectangular shaped spray area

$$D_s = K\left(\frac{W}{s_w}\right)L = \underline{(\qquad)}\ \frac{(\qquad)}{(\qquad)}\ \underline{(\qquad)}$$

D_s = ____________________ mi or km

Where L is the length of the side of the rectangle paralleled by the spray path and W is the length of the remaining side, and where K = 5280 if dimensions in mi and ft or K = 1000 if dimensions in km or m.

Step 7. Number of Spray Cycles, N_c. (Round up)

$$N_c = \frac{D_s}{d_s} = \frac{(\qquad\qquad)}{(\qquad\qquad)}$$

N_c = __________________________________

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
		Total (for item 9) N_s =	Sum (ft or m) D_s =
		Tot. No. Paths =	Sum* (mi or km) D_s =
			Tot. D_s =

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Step 8. Data Sheet for Total Spray Cycle Ferry Distance, D_f (mi or km).
(The use of this sheet is optional.)

The spray cycle ferry distances, d_f, including the ferry distances within the cycle are obtained from the scaled layout and are to be entered in the table below.

Cycle Number n	From local base to starting point d_f (mi, or km)	From ending point to local base d_f (mi, or km)	Ferry distance within the cycle d_f (mi, or km)
Totals			

D_f = Sum of the totals.

= ________ + ________ + ________

D_f = ________ mi or km.

Step 9. Total Number of Turns, N_t

For a nonrectangular shaped spray area N_s is the sum appearing at the bottom of column 2 of the worksheet for item 6. If more than one such worksheet is required, N_s is the total of the sums.

N_s = ______________________

$N_f = 2N_c = 2$ (______) = _______, and N_a = ______

$N_t = N_s + N_f + N_a$ = (______) + (______) + (______)

N_t = __________________________

For a rectangular shaped spray area*

$N_s = K_t \frac{W}{s_w}$ = (_____) $\frac{(\_\_\_\_\_)}{(\quad\quad)}$ = _______ (K_t = 5280 if dimensions are in ft and mi or K_t = 1000 if dimensions are in m and km)

$N_f = 2N_c = 2$ (_____) = _____, and N_a = _______________

$N_t = N_s + N_f + N_a$ = (______) + (_____) + (______)

N_t = ____________

Step 10a. Total Ferry Time, T_f (min)

$$T_f = 60 \frac{(D_f + d_a)}{v_f} = 60 \frac{(\quad\quad + \quad\quad)}{(\quad\quad)}$$

T_f = _______________ min

Step 10b. Total Spray Time, T_s (min)

$$T_s = 60 \frac{D_s}{v_s} = 60 \left(\frac{\quad\quad}{\quad\quad} \right)$$

T_s = _____________________________ min

*In this calculation, W is the length of the side of the rectangle, which side is perpendicular to the direction of the spray path.

Step 10c. Total Turning Time, T_t (min)

$$T_t = \frac{N_t t_t}{60} = (\_\_\_\_\_)\ (\_\_\_\_\_)\ /60$$

$$T_t = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \text{min}$$

Step 11. Total Touchup Time, T_u (min)

$$T_u = k_u\ (T_s + T_t) = (\_\_\_\_\_)\ (\_\_\_\_\_ + \_\_\_\_\_)$$

$$T_u = \_\_\_\_\_\_\_\_ \text{min}$$

Step 12. Total Loading Time, T_ℓ (min)

$$T_\ell = N_c\ t_\ell = (\_\_\_\_\_)\ (\_\_\_\_\_)$$

$$T_\ell = \_\_\_\_\_\_\_\_\_\_ \text{min}$$

Step 13. Total Flying Time, T_o (min)

$$T_o = T_s + T_f + T_t + T_u = (\_\_\_\_\_) + (\_\_\_\_\_) + (\_\_\_\_\_) + (\_\_\_\_\_)$$

$$T_o = \_\_\_\_\_\_\_\_\_\_ \text{min}$$

Step 14. Total Operation Time, T_T (min)

$$T_T = T_o + T_\ell = (\_\_\_\_\_) + (\_\_\_\_\_)$$

$$T_T = \_\_\_\_\_\_\_\_\_\_ \text{min}$$

Step 15. Total Flying Costs, C_o.

$$C_o = (c_s T_s + c_f T_f + c_t T_t + c_u T_u)/60$$

$$= \left[(\_\_\_\_)(\_\_\_\_)+(\_\_\_\_)(\_\_\_\_)+(\_\_\_\_)(\_\_\_\_)+(\_\_\_\_)(\_\_\_\_)\right]/60$$

$$C_o = \_\_\_\_\_\_\_\_ \text{dollars}$$

Step 16. Total Loading Cost, C_ℓ

$$C_\ell = (T_\ell c_\ell)/60 = \frac{(\_\_\_\_)}{60}\ (\_\_\_\_)$$

C_ℓ = __________dollars

Step 17. Productivity, PROD

$$PROD = 60\ A_s/T_T = 60\ (\_\_\_\_)\ /\ (\_\_\_\_)$$

PROD = ____________ac/hr or ha/hr

Step 18. Efficiency, EFF

$$EFF = 100 \quad (T_s + T_u)/T_T = 100\ (\_\_\_\_\_ + \_\_\_\_\_)/(\_\_\_\_\_\_)$$

EFF = ______________________%

Step 19. Total Cost, C_T

$$C_T = C_o + C_\ell = (\_\_\_\_\_) + (\_\_\_\_\_)$$

C_T = ___________dollars

Step 20. Total Operation Cost/Hour, R_t

$$R_t = 60\ C_T/T_T = 60\ (\_\_\_\_)\ /\ (\_\_\_\_)$$

R_t = _____\$/hr

Step 21. Total Operation Cost/ac or Cost/ha, R_a

$$R_a = C_T/A_s = (\_\_\_\_)/(\_\_\_\_)$$

R_a = _________\$/ac or \$/ha

Example No. 1

Use of the Rectangular Approximation

Assume that a single helicopter is used to spray an area which may be approximated by a rectangle. The area is to be sprayed from a helispot adjacent to the spray area and the following data is prescribed:

1. The direct ferry distance, d_f is 30 miles.

2. The total auxiliary ferry distance, d_a is 90 miles.

3. A single cycle is required to spray the area, and the spray path is parallel to the longest side of the rectangle.

4. The remaining prescribed data is as given on the input data sheet (see page 25). Because target is rectangular in shape, no layout is needed. It is assumed that the ferry distances from the local base to the starting point and from the ending point to the local base are the same.

[illegible] ... fly, [illegible] the following data is prescribed:

The direct ferry distance, d_F is [illegible] miles.

The [illegible] ferry distance, d_F is [illegible] miles.

[illegible] single cycle is required to cover the area, and the [illegible] to the longest side of the rectangle.

The remaining prescribed data is given on the [illegible] data sheet [illegible] because [illegible] that the ferry distances from the local base to the starting [illegible] from the ending point to the locus [illegible] the [illegible].

Input Data Sheet

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	
Target Dim**	mi or km	L, W	$3\frac{3}{8} \times 1\frac{3}{4}$ mi
Application Rate	g/Ac or l/ha	a_r	1.5 g/Ac
Tank Capacity	g or l	Q_f	275 g
Swath Width	ft or m	s_w	75 ft
Spray Speed	mi/hr or km/hr	v_s	90 mi/hr
Ferry Speed	mi/hr or km/hr	v_f	90 mi/hr
Turning Time	sec	t_t	36 sec
Aux. Ferry Dis.	mi or km	d_a	90 mi
Touchup Const. of Prop.		k_u	0.1
Spraying Cost Rate	$/hr	c_s	200 $/hr
Ferrying Cost Rate	$/hr	c_f	200 $/hr
Turning Cost Rate	$/hr	c_t	200 $/hr
Touchup Cost Rate	$/hr	c_u	200 $/hr
Loading Cost Rate	$/hr	c_ℓ	200 $/hr
Loading Time/Cycle	min	t_ℓ	15 min

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Worksheet

Some of the calculations are considerably simplified if a rectangular approximation to the target area is permitted. Separate calculation steps for these cases are given.

Step 1. Target Area, A_s

A_s = ______________________ Ac or ha

Rectangular shaped spray area

a. L and W in miles

$A_s = 640\ LW = 640\ (3\tfrac{3}{8})\ (1\tfrac{3}{4}) = 3780$ ac

b. L and W in km

$A_s = 100\ LW = 100\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ha

Step 4. Pesticide Flow Rate, f_r (g/min or l/min)

$f_r = c_r a_r v_s s_w$

$= (0.00202)\ (1.5)\ (90)\ (75)$

f_r = 20.45 g/min or l/min

where: $c_r = \frac{1}{495}$, if a_r in g/ac, v_s in mi/hr and s_w in ft or

$c_r = \frac{1}{600}$, if a_r in l/ha, v_s in km/hr and s_w in m.

Step 5. Spray Distance per Cycle, d_s (mi or km)

$$d_s = \frac{Q_f v_s}{60 f_r} = \frac{(275)\ (90)}{60(20.45)}$$

d_s = 20.17 mi or km

> Note: d_s in mi or km according to the units of Q_f, v_s, and f_r. These units must be compatible.

Step 6. Total Spray Distance, D_s (mi or km)

This calculation is made in accord with the discussion concerning step 6 of the procedures. The accompanying worksheet may be used as an aid. The sum called for at the bottom of the third column is the sum of the total lengths of the associated spray paths. If more than one worksheet is used, D_s is the total of the sums appearing at the bottom of each worksheet. The sum of the numbers appearing in the second column is the required number of turns for spraying (see item 9).

D_s = ________________ mi or km

Rectangular shaped spray area

$$D_s = K \left(\frac{W}{s_w}\right) L = \frac{(5280)}{} \; \frac{(3\tfrac{3}{8})}{(75)} \; \frac{(1\tfrac{3}{4})}{}$$

D_s = 415.8 mi or km

Where L is the length of the side of the rectangle paralleled by the spray path and W is the length of the remaining side, and where K = 5280 if dimensions in mi and ft or K = 1000 if dimensions in km or m.

Step 7. Number of Spray Cycles, N_c. (Round up)

$$N_c = \frac{D_s}{d_s} = \frac{(415.8)}{(20.17)}$$

N_c = 21

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
		Total (for item 9) N_s =	Sum (ft or m) D_s =
		Tot. No. Paths =	Sum* (mi or km) D_s =
			Tot. D_s =

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Step 8. Data Sheet for Total Spray Cycle Ferry Distance, D_f (mi or km).
(The use of this sheet is optional.)

The spray cycle ferry distances, d_f, including the ferry distances within the cycle are obtained from the scaled layout and are to be entered in the table below.

Cycle Number n	From local base to starting point d_f (mi, or km)	From ending point to local base d_f (mi, or km)	Ferry distance within the cycle d_f (mi, or km)
1	30	30	0
Totals			

D_f = Sum of the totals.

= 30 + 30 + 0

D_f = 60 mi or km.

Step 9. Total Number of Turns, N_t

For a nonrectangular shaped spray area N_s is the sum appearing at the bottom of column 2 of the worksheet for item 6. If more than one such worksheet is required, N_s is the total of the sums (round up).

N_s = ____________________

$N_f = 2N_c = 2$ (______) = _______, and N_a = ______

$N_t = N_s + N_f + N_a$ = (______) + (______) + (______)

N_t = ________________________

For a rectangular shaped spray area*

$N_s = K_t \frac{W}{s_w}$ = $\frac{(5280)\ (1\,3/4)}{(75)}$ = 124 (K_t = 5280 if dimensions are in ft and mi or K_t = 1000 if dimensions are in m and km)

$N_f = 2N_c = 2$ (21) = 42, and N_a = 2

$N_t = N_s + N_f + N_a$ = (124) + (42) + (2)

N_t = 168

Step 10a. Total Ferry Time, T_f (min)

$$T_f = 60 \frac{(D_f + d_a)}{v_f} = 60 \left(\frac{60 + 90}{(90)}\right)$$

T_f = 100 min

Step 10b. Total Spray Time, T_s (min)

$$T_s = 60 \frac{D_s}{v_s} = 60 \left(\frac{415.8}{90}\right)$$

T_s = 277.2 min

*In this calculation, W is the length of the side of the rectangle, which side is perpendicular to the direction of the spray path.

Step 10c. Total Turning Time, T_t (min)

$$T_t = \frac{N_t t_t}{60} = (\underline{168})\ (\underline{36})\ /60$$

$$T_t = \underline{100.8} \text{ min}$$

Step 11. Total Touchup Time, T_u (min)

$$T_u = k_u\ (T_s + T_t) = (\underline{0.1})\ (\underline{277.2} + \underline{100.8})$$

$$T_u = \underline{37.8} \text{ min}$$

Step 12. Total Loading Time, T_ℓ (min)

$$T_\ell = N_c\ t_\ell = (\underline{21})\ (\underline{15})$$

$$T_\ell = \underline{315} \text{ min}$$

Step 13. Total Flying Time, T_o (min)

$$T_o = T_s + T_f + T_t + T_u = (\underline{277.2}) + (\underline{100}) + (\underline{100.8}) + (\underline{37.8})$$

$$T_o = \underline{515.8} \text{ min}$$

Step 14. Total Operation Time, T_T (min)

$$T_T = T_o + T_\ell = (\underline{515.8}) + (\underline{315})$$

$$T_T = \underline{830.8} \text{ min}$$

Step 15. Total Flying Costs, C_o.

$$C_o = (c_s T_s + c_f T_f + c_t T_t + c_u T_u)/60$$

$$= \left[(\underline{200})\ (\underline{277.2}) + (\underline{200})\ (\underline{100}) + (\underline{200})\ (\underline{100.8}) + (\underline{200})\ (\underline{37.8})\right]/60$$

$$C_o = \underline{171933} \text{ dollars}$$

Step 16. Total Loading Cost, C_ℓ

$C_\ell = (T_\ell c_\ell)/60 = \frac{(315)\ (200)}{60}$

C_ℓ = 1,050 dollars

Step 17. Productivity, PROD

PROD = 60 A_s/T_T = 60 (3780) / (830.8)

PROD = 273 ac/hr or ha/hr

Step 18. Efficiency, EFF

EFF = 100 $(T_s + T_u)/T_T$ = 100 (277.2 + 37.8)/(830.8)

EFF = 37.9 %

Step 19. Total Cost, C_T

$C_T = C_o + C_\ell$ = (1,719.33) + (1050)

C_T = 2,769.33 dollars

Step 20. Total Operation Cost/Hour, R_t

R_t = 60 C_T/T_T = 60 (2,769.33) / (830.8)

R_t = 200 \$/hr

Step 21. Total Operation Cost/ac or Cost/ha, R_a

$R_a = C_T/A_s$ = (2769.33)/(3780)

R_a = 0.73 \$/ac or \$/ha

Example No. 2

Assumptions

1. The area to be sprayed is that shown in figure 3.

2. The number of spray cycles is to be estimated from a scale drawing depicting the spray lines. Each of the spray lines corresponds to approximated actual spray paths.

3. A single helicopter is to be used. It is to be flown from the nearby helispot indicated in figure 3.

4. The helicopter is to be ferried to the helispot from an overnight airbase, a distance of 45 miles. Thus, the auxiliary ferry distance, d_a, is 90 miles.

5. The relevant data for the operation is as shown on the data sheet.

Example 2

Input Data Sheet

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	715
Target Dim**	mi or km	L, W	
Application Rate	g/Ac or l/ha	a_r	2 1/4 g/Ac
Tank Capacity	g or l	Q_f	500 g
Swath Width	ft or m	s_w	40 ft
Spray Speed	mi/hr or km/hr	v_s	90 mi/hr
Ferry Speed	mi/hr or km/hr	v_f	150 mi/hr
Turning Time	sec	t_t	15
Aux. Ferry Dis.	mi or km	d_a	90 mi
Touchup Const. of Prop.		k_u	0.2
Spraying Cost Rate	$/hr	c_s	300
Ferrying Cost Rate	$/hr	c_f	250
Turning Cost Rate	$/hr	c_t	250
Touchup Cost Rate	$/hr	c_u	300
Loading Cost Rate	$/hr	c_ℓ	150
Loading Time/Cycle	min	t_ℓ	20

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Worksheet

Some of the calculations are considerably simplified if a rectangular approximation to the target area is permitted. Separate calculation steps for these cases are given.

Step 1. Target Area, A_s

A_s = 715 Ac or ha

Rectangular shaped spray area

a. L and W in miles

$A_s = 640\ LW = 640\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ac

b. L and W in km

$A_s = 100\ LW = 100\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ha

Step 4. Pesticide Flow Rate, f_r (g/min or l/min)

$$f_r = c_r a_r v_s s_w$$

$$= (0.00202)\ (2\tfrac{1}{4})\ (90)\ (40)$$

f_r = 16.36 g/min or l/min

where: $c_r = \frac{1}{495}$, if a_r in g/ac, v_s in mi/hr and s_w in ft or

$c_r = \frac{1}{600}$, if a_r in l/ha, v_s in km/hr and s_w in m.

Step 5. Spray Distance per Cycle, d_s (mi or km)

$$d_s = \frac{Q_f v_s}{60 f_r} = \frac{(500)\ (90)}{60\,(16.36)}$$

d_s = 45.84 mi or km

Note: d_s in mi or km according to the units of Q_f, v_s, and f_r. These units must be compatible.

Step 6. Total Spray Distance, D_s (mi or km)

This calculation is made in accord with the discussion concerning step 6 of the procedures. The accompanying worksheet may be used as an aid. The sum called for at the bottom of the third column is the sum of the total lengths of the associated spray paths. If more than one worksheet is used, D_s is the total of the sums appearing at the bottom of each worksheet. The sum of the numbers appearing in the second column is the required number of turns for spraying (see item 9).

D_s = 147.3 mi or km

Rectangular shaped spray area

$$D_s = K\left(\frac{W}{s_w}\right)L = (\quad)\ \frac{(\quad)}{(\quad)}\ (\quad)$$

D_s = ______ mi or km

Where L is the length of the side of the rectangle paralleled by the spray path and W is the length of the remaining side, and where K = 5280 if dimensions in mi and ft or K = 1000 if dimensions in km or m.

Step 7. Number of Spray Cycles, N_c. (Round up)

$$N_c = \frac{D_s}{d_s} = \frac{(147.3)}{(45.84)}$$

N_c = 4

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
1	6,500	6	39,000
2	6,000	6	36,000
3	5,750	8	46,000
4	5,750	7	40,250
5	5,500	6	33,000
6	5,300	7	37,100
7	4,850	8	38,800
8	4,850	8	38,800
9	4,750	7	33,250
10	4,900	7	34,300
11	1,750	7	12,250
12	1,350	5	6,750
		Total (for item 9) N_s = 82	Sum (ft or m) D_s = 395,500 ft
			Sum* (mi or km) D_s = 74.91 mi

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Example 2

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
13	4,750	7	33,250
14	5,250	7	36,750
15	7,500	5	37,500
16	6,750	5	33,750
17	6,500	6	39,000
18	6,250	7	43,750
19	1,375	6	8,250
20	1,375	7	9,625
21	6,250	8	50,000
22	4,750	7	33,250
23	5,175	7	36,225
24	4,150	4	16,600
25	850	5	4,250
		Total (for item 9) N_s = 81	Sum (ft or m) D_s = 382,200 Ft
		Tot. No. Paths = 163	Sum* (mi or km) D_s = 72.39 mi

Tot. D_s = 147.3 mi

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Step 8. Data Sheet for Total Spray Cycle Ferry Distance, D_f (mi or km).
(The use of this sheet is optional.)

The spray cycle ferry distances, d_f, including the ferry distances within the cycle are obtained from the scaled layout and are to be entered in the table below.

Cycle Number n	From local base to starting point d_f (mi, or km)	From ending point to local base d_f (mi, or km)	Ferry distance within the cycle d_f (mi, or km)
1	1.1	0.9	2
2	0.9	1.1	
3	1.1	0.7	
4	0.7	0.5	
Totals	3.8	3.2	2

D_f = Sum of the totals.

= 3.8 + 3.2 + 2

D_f = 9 mi or km.

Step 9. Total Number of Turns, N_t

For a nonrectangular shaped spray area N_s is the sum appearing at the bottom of column 2 of the worksheet for item 6. If more than one such worksheet is required, N_s is the total of the sums (round up).

N_s = 163

$N_f = 2N_c = 2$ (4) = 8, and N_a = 2

$N_t = N_s + N_f + N_a$ = (163) + (8) + (2)

N_t = 173

For a rectangular shaped spray area*

$N_s = K_t \frac{W}{s_w}$ = (____) $\frac{(\_\_\_\_)}{(\_\_\_\_)}$ = ____ (K_t = 5280 if dimensions are in ft and mi or K_t = 1000 if dimensions are in m and km)

$N_f = 2N_c = 2$ (____) = ____, and N_a = ____

$N_t = N_s + N_f + N_a$ = (____) + (____) + (____)

N_t = ____

Step 10a. Total Ferry Time, T_f (min)

$$T_f = 60 \frac{(D_f + d_a)}{v_f} = 60 \left(\frac{9 + 90}{(150)}\right)$$

T_f = 39.6 min

Step 10b. Total Spray Time, T_s (min)

$$T_s = 60 \frac{D_s}{v_s} = 60 \left(\frac{147.3}{90}\right)$$

T_s = 98.2 min

*In this calculation, W is the length of the side of the rectangle, which side is perpendicular to the direction of the spray path.

Step 10c. Total Turning Time, T_t (min)

$$T_t = \frac{N_t t_t}{60} = (\underline{173})\ (\underline{15})\ /60$$

$$T_t = \underline{43.25}\ \text{min}$$

Step 11. Total Touchup Time, T_u (min)

$$T_u = k_u\ (T_s + T_t) = (\underline{0.2})\ \ (\underline{98.2} + \underline{43.25})$$

$$T_u = \underline{28.3}\ \text{min}$$

Step 12. Total Loading Time, T_ℓ (min)

$$T_\ell = N_c\ t_\ell = (\underline{4})\ (\underline{20})$$

$$T_\ell = \underline{80}\ \text{min}$$

Step 13. Total Flying Time, T_o (min)

$$T_o = T_s + T_f + T_t + T_u = (\underline{98.2}) + (\underline{39.6}) + (\underline{43.25}) + (\underline{28.3})$$

$$T_o = \underline{209.35}\ \text{min}$$

Step 14. Total Operation Time, T_T (min)

$$T_T = T_o + T_\ell = (\underline{209.35}) + (\underline{80})$$

$$T_T = \underline{289.35}\ \text{min}$$

Step 15. Total Flying Costs, C_o.

$$C_o = (c_s T_s + c_f T_f + c_t T_t + c_u T_u)/60$$

$$= \left[(\underline{300})(\underline{98.2}) + (\underline{250})(\underline{39.6}) + (\underline{250})(\underline{43.25}) + (\underline{300})(\underline{28.3})\right]/60$$

$$C_o = \underline{977.70}\ \text{dollars}$$

Step 16. Total Loading Cost, C_ℓ

$C_\ell = (T_\ell c_\ell)/60 = \frac{(80)}{60}(150)$

C_ℓ = 200 dollars

Step 17. Productivity, PROD

PROD = 60 A_s/T_T = 60 (715) / (289.35)

PROD = 148.3 ac/hr or ha/hr

Step 18. Efficiency, EFF

EFF = 100 $(T_s + T_u)/T_T$ = 100 (98.2 + 28.3)/(289.35)

EFF = 43.72 %

Step 19. Total Cost, C_T

$C_T = C_o + C_\ell$ = (977.20) + (200)

C_T = 1,177.20 dollars

Step 20. Total Operation Cost/Hour, R_t

$R_t = 60\ C_T/T_T$ = 60 (1,177.20 / (289.35)

R_t = 244.11 $/hr

Step 21. Total Operation Cost/ac or Cost/ha, R_a

$R_a = C_T/A_s$ = (1,177.20)/(715)

R_a = 1.65 $/ac or $/ha

Example No. 3

Assumptions

1. A single helicopter is used and the aerial spray layout is depicted in figure 4.

2. There are two areas to be sprayed. The areas are designated Area 1 and Area 2, respectively. The spray starting points are labeled S_1 and S_2. See the accompanying drawing of the target areas.

3. There are two helispots, designated HS 1 and HS 2.

4. The spray paths are as indicated in the figure.

5. A heavy dot with an arrow indicates the end of a spray cycle. The accompanying integer indicates the spray cycle.

6. The helicopter is to be ferried from its home base, a distance of 10 kilometers. Thus, d_a = 20 km.

7. The relevant data are as shown on the data sheet.

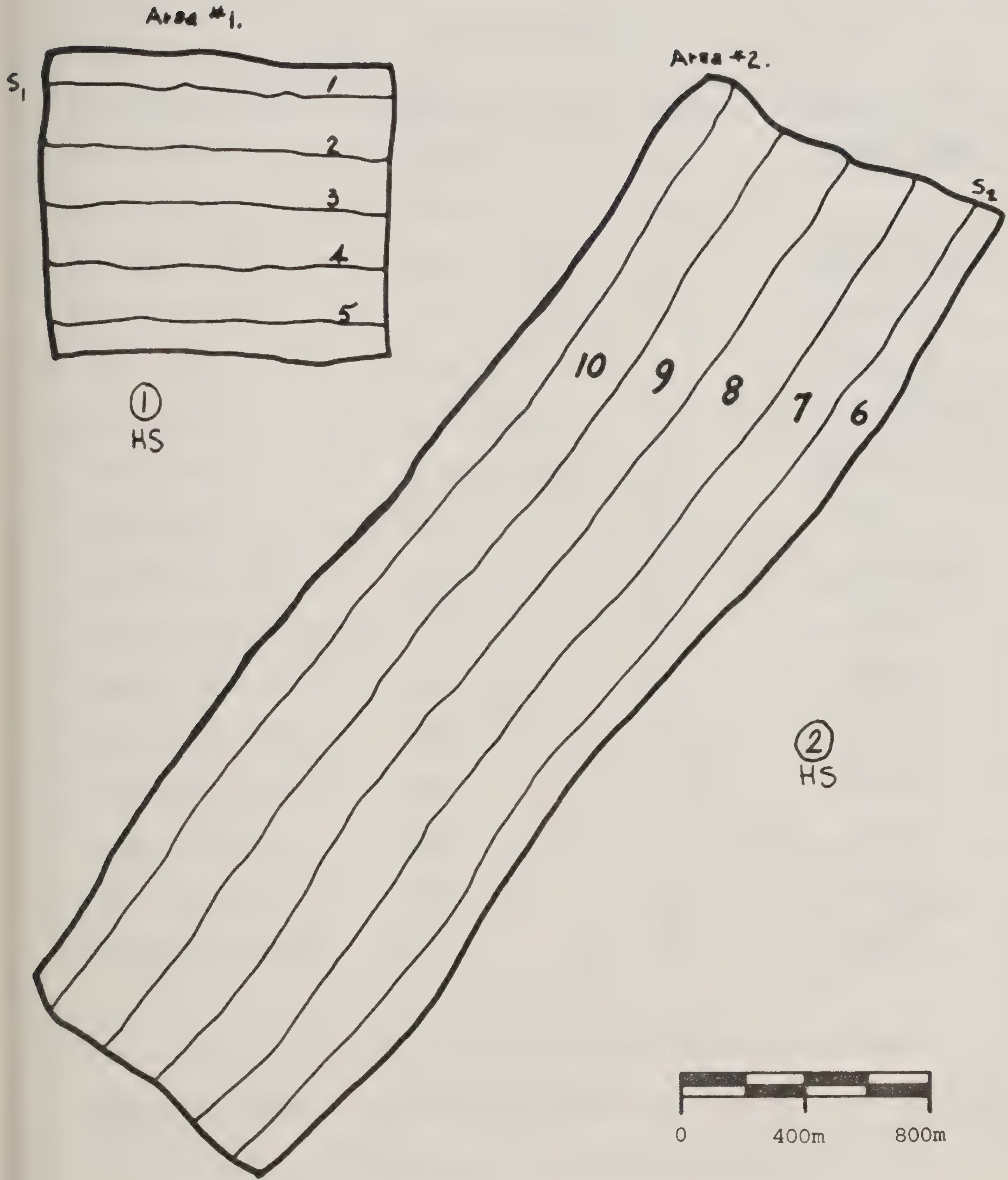

Figure 4.--Aerial spray layout for Example 3.

Example 3

Input Data Sheet

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	440 ha
Target Dim**	mi or km	L, W	
Application Rate	g/Ac or l/ha	a_r	6 l/ha
Tank Capacity	g or l	Q_f	1,200 l
Swath Width	ft or m	s_w	60 m
Spray Speed	mi/hr or km/hr	v_s	240 km/h
Ferry Speed	mi/hr or km/hr	v_f	250 km/h
Turning Time	sec	t_t	24
Aux. Ferry Dis.	mi or km	d_a	20 km
Touchup Const. of Prop.		k_u	0.2
Spraying Cost Rate	$/hr	c_s	300
Ferrying Cost Rate	$/hr	c_f	275
Turning Cost Rate	$/hr	c_t	290
Touchup Cost Rate	$/hr	c_u	300
Loading Cost Rate	$/hr	c_ℓ	150
Loading Time/Cycle	min	t_ℓ	25

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Worksheet

Some of the calculations are considerably simplified if a rectangular approximation to the target area is permitted. Separate calculation steps for these cases are given.

Step 1. Target Area, A_s

A_s = 440 Ac or ha

Rectangular shaped spray area

a. L and W in miles

$A_s = 640\ LW = 640\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ac

b. L and W in km

$A_s = 100\ LW = 100\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ha

Step 4. Pesticide Flow Rate, f_r (g/min or l/min)

$f_r = c_r a_r v_s s_w$

$= (0.00167)\ (6)\ (240)\ (60)$

f_r = 144.3 g/min or l/min

where: $c_r = \frac{1}{495}$, if a_r in g/ac, v_s in mi/hr and s_w in ft or

$c_r = \frac{1}{600}$, if a_r in l/ha, v_s in km/hr and s_w in m.

Step 5. Spray Distance per Cycle, d_s (mi or km)

$$d_s = \frac{Q_f v_s}{60 f_r} = \frac{(1200)\ (240)}{60\,(144.3)}$$

d_s = 33.3 mi or km

Note: d_s in mi or km according to the units of Q_f, v_s, and f_r. These units must be compatible.

Step 6. Total Spray Distance, D_s (mi or km)

This calculation is made in accord with the discussion concerning step 6 of the procedures. The accompanying worksheet may be used as an aid. The sum called for at the bottom of the third column is the sum of the total lengths of the associated spray paths. If more than one worksheet is used, D_s is the total of the sums appearing at the bottom of each worksheet. The sum of the numbers appearing in the second column is the required number of turns for spraying (see item 9).

D_s = 73.14 mi or km

Rectangular shaped spray area

$$D_s = K \left(\frac{W}{s_w}\right) L = \underline{(\qquad)}\ \frac{(\qquad)}{(\qquad)}\ \underline{(\qquad)}$$

D_s = ____________ mi or km

Where L is the length of the side of the rectangle paralleled by the spray path and W is the length of the remaining side, and where K = 5280 if dimensions in mi and ft or K = 1000 if dimensions in km and m.

Step 7. Number of Spray Cycles, N_c. (Round up)

$$N_c = \frac{D_s}{d_s} = \frac{(\ 73.14\ )}{(\ 33.3\ )}$$

N_c = 3

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
1	1,140	3	3,420
2	1,140	3	3,420
3	1,120	3	3,360
4	1,090	3	3,270
5	1,080	3	3,240
6	3,880	3	11,640
7	3,880	3	11,640
8	3,770	3	11,190
9	3,680	3	11,040
10	3,640	3	10,920
		Total (for item 9) N_s = 30	Sum (ft or m) D_s = 73,140
			Sum* (mi or km) D_s = 73.14

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Step 8. Data Sheet for Total Spray Cycle Ferry Distance, D_f (mi or km).
(The use of this sheet is optional.)

The spray cycle ferry distances, d_f, including the ferry distances within the cycle are obtained from the scaled layout and are to be entered in the table below.

Cycle Number n	From local base to starting point d_f (mi, or km)	From ending point to local base d_f (mi, or km)	Ferry distance within the cycle d_f (mi, or km)
1	1.1	0.6	2
2	0.6	2.0	
3	2.0	2.1	
Totals	3.7	4.8	2

D_f = Sum of the totals.

= 3.7 + 4.8 + 2

D_f = 10.5 mi or km.

Step 9. Total Number of Turns, N_t

For a nonrectangular shaped spray area, N_s is the sum appearing at the bottom of column 2 of the worksheet for item 6. If more than one such worksheet is required, N_s is the total of the sums (round up).

N_s = 30

$N_f = 2N_c = 2$ (3) = 6, and N_a = 2

$N_t = N_s + N_f + N_a$ = (30) + (6) + (2)

N_t = 38

For a rectangular shaped spray area*

$N_s = K_t \dfrac{W}{s_w}$ = (____) (____) / (____) = ______ (K_t = 5280 if dimensions are in ft and mi or K_t = 1000 if dimensions are in m and km)

$N_f = 2N_c = 2$ (____) = ____, and N_a = ________

$N_t = N_s + N_f + N_a$ = (____) + (____) + (____)

N_t = ________

Step 10a. Total Ferry Time, T_f (min)

$$T_f = 60 \frac{(D_f + d_a)}{v_f} = 60 \left(\frac{10.5 + 20}{250}\right)$$

T_f = 7.3 min

Step 10b. Total Spray Time, T_s (min)

$$T_s = 60 \frac{D_s}{v_s} = 60 \left(\frac{73.14}{240}\right)$$

T_s = 18.3 min

*In this calculation, W is the length of the side of the rectangle, which side is perpendicular to the direction of the spray path.

Step 10c. Total Turning Time, T_t (min)

$$T_t = \frac{N_t t_t}{60} = (\underline{38})(\underline{24})/60$$

$$T_t = \underline{15.2} \text{ min}$$

Step 11. Total Touchup Time, T_u (min)

$$T_u = k_u (T_s + T_t) = (\underline{0.2})(\underline{18.3} + \underline{15.2})$$

$$T_u = \underline{6.7} \text{ min}$$

Step 12. Total Loading Time, T_ℓ (min)

$$T_\ell = N_c t_\ell = (\underline{3})(\underline{25})$$

$$T_\ell = \underline{75} \text{ min}$$

Step 13. Total Flying Time, T_o (min)

$$T_o = T_s + T_f + T_t + T_u = (\underline{18.3}) + (\underline{7.3}) + (\underline{15.2}) + (\underline{6.7})$$

$$T_o = \underline{47.5} \text{ min}$$

Step 14. Total Operation Time, T_T (min)

$$T_T = T_o + T_\ell = (\underline{47.5}) + (\underline{75})$$

$$T_T = \underline{122.5} \text{ min}$$

Step 15. Total Flying Costs, C_o.

$$C_o = (c_s T_s + c_f T_f + c_t T_t + c_u T_u)/60$$

$$= \left[(\underline{300})(\underline{18.3}) + (\underline{275})(\underline{7.3}) + (\underline{290})(\underline{15.2}) + (\underline{300})(\underline{6.7})\right]/60$$

$$C_o = \underline{231.9} \text{ dollars}$$

Step 16. Total Loading Cost, C_ℓ

$C_\ell = (T_\ell c_\ell)/60 = \frac{(75)\ (150)}{60}$

C_ℓ = 187.5 dollars

Step 17. Productivity, PROD

PROD = 60 A_s/T_T = 60 (440) / (122.5)

PROD = 215.5 ac/hr or ha/hr

Step 18. Efficiency, EFF

EFF = 100 $(T_s + T_u)/T_T$ = 100 (18.3 + 6.7)/(122.5)

EFF = 20.4 %

Step 19. Total Cost, C_T

$C_T = C_o + C_\ell$ = (231.9) + (187.5)

C_T = 419.4 dollars

Step 20. Total Operation Cost/Hour, R_t

R_t = 60 C_T/T_T = 60 (419.4) / (122.5)

R_t = 205.4 \$/hr

Step 21. Total Operation Cost/ac or Cost/ha, R_a

$R_a = C_T/A_s$ = (419.4)/(440)

R_a = 0.95 \$/ac or \$/ha

A PLANNING AID EXAMPLE

By comparing the spray efficiency and the spray productivity corresponding to different sets of aircraft spray and flight characteristics, it is possible to select the optimum aircraft and spray characteristics for a specified aerial spray operation. In this way the procedure is an aid as a planning tool for the aerial spray designer.

The following is an example of how the procedure can be used to evaluate different aircraft for an aerial spray operation. Let the area to be sprayed, as well as the application rate, be that which is specified in example 1. Let the flight characteristics and operating costs of aircraft A be the same as those listed in example 1. The flight characteristics and operating costs of aircraft B are given in table 1. Aircraft C is identical with aircraft B except the former furnishes a 75-foot spray swath rather than a 90-foot spray swath.

Table 2 contains a summary of the relevant calculations obtained by applying the calculation procedure to each of the three aircraft

Table 1. -- Input Data Sheet (Aircraft B & C)

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	
Target Dim**	mi or km	L, W	3 3/8 x 1 3/4 mi
Application Rate	g/Ac or l/ha	a_r	1.5 g/Ac
Tank Capacity	g or l	Q_f	400 g
Swath Width	ft or m	s_w	90 ft
Spray Speed	mi/hr or km/hr	v_s	120 MPH
Ferry Speed	mi/hr or km/hr	v_f	120 MPH
Turning Time	sec	t_t	36 seL
Aux. Ferry Dis.	mi or km	d_a	90 mi
Touchup Const. of Prop.		k_u	0.1
Spraying Cost Rate	$/hr	c_s	220 $/hr
Ferrying Cost Rate	$/hr	c_f	220 $/hr
Turning Cost Rate	$/hr	c_t	220 $/hr
Touchup Cost Rate	$/hr	c_u	220 $/hr
Loading Cost Rate	$/hr	c_ℓ	220 $/hr
Loading Time/Cycle	min	t_ℓ	20

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Table 2. -- Summary Calculations

	Aircraft A	Aircraft B	Aircraft C
Hourly Costs, $c_s=c_f=c_t=c_u=c_\ell$	200 \$/hr	220 \$/hr	220 \$/hr
Spray Speed v_s	90 mph	120 mph	120 mph
Ferry Speed v_f			
Swath Width, s_w	75 ft	90 ft	75 ft
Total Operation Time - T_t	830.8 min	654.7 min	770.6 min
Total Flying Costs - C_o	\$1719.33	\$1300.48	\$1505.53
Total Loading Costs - C_ℓ	\$1050.00	\$1100.00	\$1320.00
Productivity - PROD	273 Ac/hr	364.4 Ac/hr	294.3 Ac/hr
Efficiency - EFF	37.9%	17.4%	30.9%
Total Cost - C_T	\$2769.33	\$2400.18	\$2825.53
Cost/hr = R_t	\$200/hr	\$220/hr	\$220/hr
Cost/Ac - R_2	\$0.73/Ac	\$0.635/hr	\$0.75/Ac

An analysis of the results in table 2 shows that:

1. The smaller, slower aircraft has the greatest efficiency. This may be explained by noting that the touch up time for each aircraft is very small in comparison to the total spraying time. Thus, since the efficiency of each aircraft is the ratio of the sum of the touch up time and the spray time to the total operation time, the longer the spraying time, the greater the efficiency. A similar result is obtained when the efficiencies of aircrafts B and C are compared. However, the productivity, that is the number of acres sprayed per hour, is the greatest for the larger aircraft with the larger spray swath. In contrast, the smaller aircraft has the least productivity. Consequently, it seems that efficiency is a measure which can be misleading if it is not correctly interpreted.

2. Aircraft B is the most productive as well as having the lowest cost per acre.

3. A comparison of the cost per acre sprayed for aircraft A with aircraft B reveals that the smaller and slower aircraft is more cost effective, though not by very much. This is due to the fact that the swath widths for each aircraft are identical and the faster aircraft is the more expensive to operate.

4. The smallest total cost is obtained by using aircraft B while aircrafts A and C have about the same cost. This is due to the fact that, for the same swath width, the corresponding increase in speed and carrying capacity cannot offset the increase in operation cost of the larger and faster aircraft.